



CHALMERS
UNIVERSITY OF TECHNOLOGY



Interior super insulation in heritage buildings

Challenges and possibilities to conserve heritage values and increase energy performance

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Report

Architecture and Civil Engineering

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Cover:

The industrial area Forsåker in Mölndal. The brick building on the left was built in 1896. It has poor energy performance but with several heritage values such as the façade with important character defining elements. Photo: Pontus Johansson.

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ABSTRACT

Super insulation materials (SIM) are insulation material with a very low thermal conductivity, even lower than stagnant air. The aim of the project has been to show how these materials can be used to save energy and space, as well as to contribute to preservation of exterior character defining elements while maintaining the temperature and humidity performance of the walls when renovating buildings built before 1945. The project was performed by researchers in the fields of building physics and building conservation. Brick buildings in Sweden have been in focus, as these buildings have one of the largest energy efficiency potentials in the entire building stock. Brick buildings often challenge engineers and architects by having contradicting demands on energy efficiency and cultural heritage values. Often, the façades of these buildings have valuable character defining elements that make them difficult to insulate. There are also problems with the building components, technical service life and insufficient thermal comfort indoors. Experts in architecture and building conservation have contributed with knowledge through interviews and practical work at study visits and by reviewing drawings and construction documents. Collaboration partners, linked to the reference group, contributed to the project with their knowledge in interviews, meetings and seminars. The project has led to an increased knowledge and understanding of the technical difficulties that exist when preserving character defining elements while imposing energy efficiency measures with super insulation materials in buildings. Advantages of super insulation materials are, for example, that they add little thickness to the walls and that the flexible materials, such as aerogel blankets, can contribute to preservation of character defining elements in heritage buildings. The disadvantage of using super insulation materials as interior insulation is, as for all insulation materials, that the lowered temperatures in the wall can lead to increased moisture levels and also that the drying out capacity of the wall can decrease. Due to the risks with interior insulation of walls, it is important to thoroughly investigate if the wall is suitable for interior insulation.

Key words: Energy efficiency, interior insulation, super insulation material, heritage values, moisture, water repellent treatment, impregnation

Invändig superisolerings i byggnader med kulturvärden

Utmaningar och möjligheter att bevara kulturvärden och öka energiprestandan

Rapport

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SAMMANFATTNING

Superisoleringsmaterial (SIM) är isoleringsmaterial som har mycket låg värmeledningsförmåga, t.o.m. lägre än stillastående luft. Syftet med projektet har varit att visa hur dessa material kan användas för att spara energi och utrymme, samt bidra till bevarande av kulturhistoriskt viktiga inslag samtidigt som temperatur- och fuktförhållanden i väggar vid renovering i byggnader byggda före 1945 hålls på en säker nivå. Projektet har genomförts av forskare inom områdena byggnadsfysik och kulturvård. Tegelbyggnader i Sverige har varit huvudfokus eftersom det är dessa byggnader som har de största energieffektivitetspotentialerna i hela byggnadsbeståndet. Tegelbyggnader utmanar ofta ingenjörer och arkitekter genom att det ställs motstående krav på energieffektivitet och bevarande av kulturvärden. Ofta har dessa byggnader fasader med värdefulla karaktärsbärande element som gör dem svåra att tilläggsisolera. Det finns också ofta problem med skador på byggnadsdelar, teknisk livslängd och bristande termisk komfort inomhus. Tilläggsisoleringens inverkan på kulturvärden har utvärderats genom intervjuer och praktiskt arbete vid studiebesök samt genom granskning av ritningar och bygghandlingar. Detta har utförts av arkitekt och byggnadsantikvarie. Projektet har lett fram till ökad kunskap om de tekniska svårigheter som finns vid bevarande av kulturvärden och energieffektivisering av byggnader med superisoleringsmaterial. Fördelarna med superisoleringsmaterial är, till exempel, att de inte ökar väggens tjocklek lika mycket som traditionella isoleringsmaterial och att de flexibla materialen, såsom aerogelfiltar, kan bidra till att bevara karaktärsbärande element i byggnader med kulturvärden. Nackdelen med att använda superisoleringsmaterial som invändig tilläggsisolering är, liksom för alla isoleringsmaterial, att den lägre temperaturen i väggen kan leda till ökade fuktnivåer och en minskning av väggens uttorkningskapacitet. På grund av riskerna med invändig tilläggsisolering av väggar är det viktigt att noggrant undersöka om väggen är lämplig för invändig tilläggsisolering.

Nyckelord: Energieffektivisering, invändig tilläggsisolering, superisoleringsmaterial, kulturhistorisk inventering, fukt, vattenavvisande skikt, hydrofobering

Preface

This report is part of the research project ‘Preserve and improve energy efficiency in listed buildings using super insulation materials’, funded by the Swedish Energy Agency (P42856-1). The project started December 1, 2016 and ended December 31, 2019. The project manager was Pär Johansson. Paula Wahlgren and Petra Eriksson (Uppsala University, Cultural Conservation) participated in the project.

A reference group has been associated with the project, which has gathered twice during the project. The group consisted of Tor Broström (Professor, Uppsala University, Conservation), Kia Bengtsson Ekström (Senior Lecturer, Chalmers, Architectural Theory and Method), Henrik Carlsson (Designer, Senior Consultant, WSP Byggprojektering), Roland Skogh (Project Manager/Facilities Manager, MölnDala Fastighets AB), Jenny Tønning (Property Developer, MölnDala Fastighets AB), Maria Alm (Indoor Environmental Specialist, City of Gothenburg, City Premises Management Board) and Maria Ros (Building Conservation Expert, White Arkitekter, Stockholm).

In addition to laboratory experiments at Chalmers University of Technology, a test facility was built in an industrial brick building from 1896 in the Forsåker area in Mölndal, where the impact of interior insulation on a brick wall was investigated. The building is owned by Mölndala Fastighets AB and is in an area with large cultural historical values.

During the project, several students worked through Bachelor’s and Master’s degree projects, and internships. Many thanks to everyone who contribute with their knowledge and time to the project.

Göteborg June 2020

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1 Introduction

The construction sector accounts for approximately 37% of the energy use in Sweden (Boverket, 2019). Around 78% of this energy is accounted to heating and cooling of buildings. The amount of energy for heating has increased the last years and was in 2016 7% higher than the average energy use in the preceding 10-year period and 8% higher than the previous year (Boverket, 2019). Around 25% of the energy for heating is used in the part of the building stock from before 1941 (Swedish Energy Agency, 2014). The focus on energy savings in society to mitigate carbon emissions, has led to implementations of several European directives on energy performance in buildings. The ongoing discussions are to enforce national renovation strategies of buildings to reach low or zero carbon dioxide emissions from the building industry by 2050.

There are many challenges associated to decreasing the energy use in existing buildings, especially in buildings located in areas of national interest for cultural heritage and for buildings that are listed. The conflict between energy efficiency and heritage values in buildings have been touched upon on in several research projects and are common in everyday practice when renovating buildings for improving energy performances. Here, one of the challenges is to reduce the energy use while not tampering with the character defining elements, such as the expression of the façade, the foundation, the volume of the building, the decoration of the façade, the windows and the window frames.

Another challenge concerns the moisture performance of the building after it is renovated. The building envelope consists of the foundation, floor, walls, windows and roof of the building. In many buildings there are other causes to perform a renovation than obtaining a low energy performance. One of the most common causes for retrofitting the building envelope is that there are acute failures in building components due to exceeded service life (Thuvander et al., 2016). In these cases, the time for planning and implementing the retrofitting measures is limited. Therefore, the optimal solution might not be chosen, neither from service life perspective, nor from life cycle cost perspective. Thus, more knowledge is needed as a basis for decision support. Often, other measures than retrofitting the building envelope are performed first, such as installing a ventilation system with heat recovery, changing the heating system to a more efficient one, and adjusting the heating system to be more in balance with the needs.

Walls can be insulated either on the interior or exterior side. Concerning moisture performance, external insulation is beneficial as this leads to an increased temperature in the construction. Unfortunately, this is not allowed in many listed buildings. Therefore, interior insulation may be the only solution. Earlier research has shown that interior insulation decreases the drying-out capacity in the outer wall and increases the risk for freeze-thaw damages in brick walls (Johansson et al., 2014a). Interior insulation will also negatively affect the heat storage capacity and the thermal inertia of the building and change the interior appearance of the wall, which is particularly important to consider for historical and/or listed buildings (Johansson et al., 2019).

One method to mitigate the decreasing drying-out capacity in the outer wall after interior insulation has been applied is to hydrophobize the external surface by using some water repellent surface treatment (impregnation). This should lead to less moisture in the construction. In this project, this was investigated by performing

hygrothermal modeling of different constructions. To complement these studies with the experiences by Swedish practitioners, five interviews with experts in the field of indoor environmental quality, renovation of buildings and water repellent surface treatments were performed.

There are several different impregnations available which can be applied to the surface of the façade to increase the water repellence. When various treatments began to be launched in the late 1970s and early 1980s, many products had low quality. At that time the treatments were used as a solution to many durability problems, often on poor materials. This led to many issues with the construction after the treatment. Among the most important drawbacks with these treatments are the limited service life of the treatment and the adverse effects on the performance of the façade if it is not completely free from cracks and other defects. It is crucial to make sure that the masonry surface is in good condition. However, it is not well known for how long the treatment works as intended, and there are rarely before and after inspections of the façade in connection with the treatment.

Conventional insulation materials have a thermal conductivity which requires a certain thickness to achieve a satisfactory thermal transmittance, U-value, of the wall. For instance, a U-value of $0.18 \text{ W/m}^2\text{K}$ corresponds to mineral wool of a thickness of approximately 220 mm. A brick wall with a thickness of 300 mm needs additional insulation of 200 mm to obtain the same U-value. This U-value is an alternative legal requirement for buildings that are renovated but that does not fulfil the energy performance requirement for the energy use of the whole building (Boverket, 2018). Therefore, it is interesting to study other, more efficient insulation materials for retrofitting purposes. Super insulation materials (SIM) are materials that have substantially lower thermal conductivity (see definition in next section) e.g. less than $25 \text{ mW/(m}\cdot\text{K)}$ (Heinemann et al., 2020). This is the thermal conductivity of stagnant air which is what creates the insulating function in most conventional insulation materials. Today, there are several SIMs on the market. In this study we focus on vacuum insulation panels (VIP) and aerogel-based composites, such as aerogel blankets (AB).

Several aspects on using SIM for building envelope retrofitting, especially exterior walls, are included in this study. Buildings from before 1945 in Sweden are targeted since these are the buildings with one of the largest energy efficiency potential of the building stock. Brick and plaster buildings are in focus since these often challenge the engineers and architect with contradicting demands on energy efficiency and cultural heritage preservation. Often, these buildings have character defining elements that make them difficult to retrofit. Also, there are problems with the building components, technical service life and unacceptable indoor thermal comfort. Interior insulation is mainly studied since this is one of the only possible solutions in many listed buildings. Nevertheless, examples on exterior insulation are also presented in this report to provide examples on how to utilize SIM in retrofitting of listed buildings.

This study aims to provide guidelines on how to develop and explore solutions that preserve historically valuable elements, leading to energy efficiency and space efficiency in buildings built before 1945. This report presents the knowledge base of retrofitting of buildings from before 1945, which have cultural heritage values and potential for energy efficiency measures on the building envelope. Information has been gathered by literature reviews, interviews with experts, workshops, case studies and large- and small-scale measurements.

2 Super insulation materials

Insulation materials are constantly being developed to improve their performance and reduce their environmental impact. New materials and solutions can contribute to improving the energy performance of historic buildings, without altering their character defining elements. Examples of these are super insulation materials (SIM) which can be divided in vacuum insulation panels (VIP) and aerogel-based composites, such as blankets (AB) (Berge and Johansson, 2012). These insulation materials have higher thermal resistance than conventional insulation materials, and thus thinner layers can be used to reach the same thermal resistance.

In IEA Annex 65 ‘Long-Term Performance of Super-Insulating Materials in Building Components & Systems’, several SIMs were investigated. Case studies were collected from all over the world. More information and conclusions are given by (Adl-Zarrabi et al., 2020). In that project, SIMs are defined as having a thermal conductivity

- below 25 mW/(m·K) if air filled such as aerogel,
- below 20 mW/(m·K) if gas filled such as gas filled panel (GFP), and
- below 15 mW/(m·K) if evacuated such as VIP.

2.1 Heat transfer in insulation materials

In general, heat transfer forced by a temperature gradient may be separated to three different physical heat transfer mechanisms (Adl-Zarrabi et al., 2020):

- convection, a transport mechanism which is related to the transport of gases or liquids,
- conduction, the energy transfer between neighboring atoms or molecules in the solid, liquid or gaseous phase, and
- radiation, long-wave infrared radiative heat transfer even in vacuum.

The first task of any porous thermal insulation material at room temperature is to suppress convection which is the most efficient heat transfer mechanism. The second task is to attenuate radiative heat transfer. As the thermal conduction of gases is much smaller than that of liquids and solids thermal insulation materials usually are highly porous. Optimization of air-filled thermal insulation materials balances between radiative heat transfer and thermal conduction via the solid molecular skeleton. Nevertheless, the conductivity of the gas in the hollow spaces is the dominant heat transfer path. Therefore, further improvements are achieved by:

1. modification of the gas - heavy gases have a lower conductivity than air - e.g. in closed-cells polyurethane (PU) foam with blowing agent,
2. reducing the size of the hollow spaces down to the mean free path of the gas molecules in the order of about 100 nm (at 25°C, atmospheric pressure), so that the heat transfer of the gas molecules is hindered by numerous collisions with the solid structure (nano-structured aerogels or fumed silica), or
3. removing the gas by evacuation. Unlike cylindrical vessels like thermos flasks, in flat evacuated elements, a filler material is necessary to bear the external atmospheric pressure. The so-called vacuum insulation panels or VIPs thus in principle are composed by an envelope and a filler or core material.

2.2 Vacuum insulation panels and aerogel-based composites

As mentioned above, two examples of SIM are VIP and AB, see Figure 1. VIP are rigid panels which cannot be cut on site and are sensitive to puncturing. Therefore, attention must be paid in the design of details and envelope components. VIP were first tested in buildings in the early 1990s which was later followed by several case studies both in laboratory and in the field. Examples of buildings with VIP in different building components were gathered in (Johansson, 2012). AB are more like conventional fiber-based insulation materials. They can be cut at the construction site and adapted to the specific measurements. These have been installed in various building assemblies since the early 2000s (Adl-Zarrabi et al., 2020).

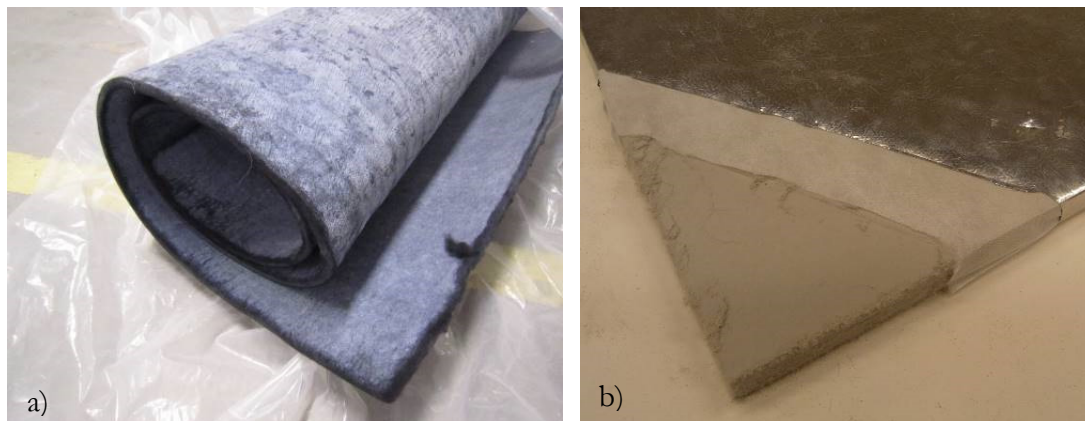


Figure 1. Super insulation materials; (a) aerogel blanket (AB), (b) vacuum insulation panel (VIP).

VIPs have different core materials (fumed silica, glass fiber, polyurethane, expanded polystyrene and others) and different envelopes (metalized film, aluminum laminate, stainless steel, glass, or combinations). The hygrothermal properties for AB and VIP differ substantially. The VIP envelope allows vapor and liquid water transfer only at the edges between the VIPs (Johansson et al., 2014a), while the vapor diffusion resistance of AB is around $\mu=5$ (-) which is a factor five higher than mineral wool. The blankets are coated with a water-repellent substance which reduce the liquid water transfer. The thermal conductivity is 0.014-0.020 W/(m·K) for AB and 0.002-0.008 W/(m·K), for VIP (Heinemann et al., 2020).

Planning renovation measures require good understanding of critical details such as connection between different materials. For VIP, also the risk of puncture must be taken into account. Depending on how the VIP is attached to the wall different protective materials can be used on the surface of the panel. It can then be glued or otherwise fixed to the surface of the wall. Small panels give less increased heat losses when puncturing, but on the other hand have a higher addition of heat flow through the thermal bridges, which has a smaller effect on the larger panels. VIP can e.g. be advantageously used as a thermal bridge breaker locally around beams and columns

Generally, all materials are suitable in different positions and with different functions. This is the same for using SIM, the purpose of using the material in a specific case must be considered. In the best case several functional requirements on energy, thermal comfort and sound/noise protection can be covered by one layer.

3 Heritage values in relation to energy efficiency measures by using super insulation materials

Historic brick buildings are often located in city centers and contributes to the architectural significance of its environment. They are also associated with different values that relate to the role of buildings in society, history, building technology, architectural expression or function. If a building is associated with these values, it is considered as a building of particular value according to the Swedish Planning and building act (Boverket, 2018). This, in turn, means that the building must not be distorted in terms of the heritage values that are designated. All changes must be made without damaging the designated values which creates limited opportunities for energy efficiency measures in historic building. In order to achieve a sound balance between energy and preservation, it is important to know why a building is important from a historic point of view and what values forms the basis for this importance. This needs to be done in a systematic and transparent way and result in a value description that also points out which character defining elements of the building need to be considered in the event of a change in the building.

One way to bridge the problem is to clarify processes and methods for how heritage values are assessed and integrated into a larger context, whether the context is planning or renovation. In recent years, different approaches and methods have been developed to create both clarity and transparency for how the impact on heritage values is assessed together with other risk factors in changing buildings, such as indoor climate, building physics, material compatibility etc. A work that summarizes this is the European standard SS-EN 16883:2017 that was developed to act as a common frame of reference and support for how energy efficiency in historic buildings can be implemented in the planning stage. Here, the management of buildings' cultural values becomes a natural part of the process, from the preparation of the knowledge base before a change to analyzing the risks that different measures of action can entail for the building in question.

An important aspect of new types of materials in historic buildings is about how compatible the materials are with the materials and constructions of the existing building. Traditional building techniques are based on the principle that the technically weakest materials are found in the outer building layers and the further into the construction you come, the stronger from a technical perspective the materials are. From a building conservation perspective, it is therefore important to study how the existing materials will interact with new types of materials, such as super insulation materials, before it is introduced as a possible method for improving certain historic buildings.

This section covers some of the methods for how heritage values in buildings are identified as part of the planning process for a renovation project. The focus is on how energy efficiency measures can be balanced with cultural values and how these can be used as a basis for deciding which measures can or cannot be applied to a historic building by using a risk-benefit analysis.

3.1 Assessing impact of energy efficiency measures on heritage values

Assessing heritage values and handle them in a building process are challenging since values often are associated with abstract and relative qualities in buildings compared with more concrete facts based on calculations. This challenge is something that needs to be overcome in order to make well-informed and balanced decisions that consider the energy-saving potential of buildings in relation to their cultural values.

The European standard SS-EN 16883:2017 has been adopted also on national level and should work like a framework for energy renovations from planning to implementation. The standard is advisory in a step by step methodology where heritage significance is considered from the initiating planning of an energy renovation process over the risk assessment of different measures on the visual, material and spatial appearance of the building to the final selection and decision on energy improving measures. It is a procedural standard that has the following basic principles:

- a cautious approach to interventions by changing as much as necessary but as little as possible,
- decisions on energy efficiency of a building should be made on a multidisciplinary ground,
- energy renovations should follow the principles of sustainable management of buildings considering the sustainability dimensions of social, environmental and economic perspectives,
- the building as a technical system, and
- user behavior.

Protected or listed buildings makes up only a small part of the total building stock in Sweden, 9500 secular buildings and 4000 religious buildings (Swedish National Heritage Board, 2015). A guideline on evaluating heritage values for the designation and preservation of historic buildings were developed in the end of the last century (Unnerbäck and Lierud, 2002). Later this guideline has partly been replaced by the more modern platform on designating and evaluating cultural heritage in a much broader societal sense, where buildings have been replaced by cultural heritage in general (Génétay and Lindberg, 2014). The difference between the older and the younger guideline lies in the approach to heritage values, from the act of designating to the process of designating.

3.2 Assessment of heritage values in renovation planning

Before renovating historic buildings an assessment of what characteristics constitutes the significant values in the building should be done according to the planning and building legislation. The implementation of this procedure is dependent on the routines in each municipal organization. The National board of housing, building and planning (Boverket) has produced web-based guidelines to help local municipalities with the interpretation. They also give recommendation on how to understand the concept of heritage values and how to adopt these values on different levels (environment, building, detail) (Boverket, n.d.). The work of defining heritage values

in renovation processes should be done by certified persons with specific knowledge about heritage and planning legislation, architectural history and building tradition. This is regulated in a specific regulation (Boverket, 2011).

In international as well as national projects that has been running energy efficiency in historic buildings and historic districts have developed guidelines, tools and different approaches on how to deal with heritage values and risk assessment in a structural way and in relation to change due to energy efficiency measures. The challenge on how to balance different interests where heritage significance is one factor has been one of the problems to solve in the EFFESUS project where data on different possible retrofit measures were characterized with the impact these will have on heritage significance. The impact data were processed in a web-based decision support system together with building data in order to get a result on an energy retrofitting strategy for buildings as well as on districts (Eriksson et al., 2014).

There have been different approaches on how to assess values and risks on historic buildings with the objective to preserve or find motives for development and change to these buildings. Most approaches are connected to the building as a technical constant with different attached or embedded values. This has in recent times been argued to be too one dimensional and expert oriented and that there is a need to lift the users and owners approach to their buildings and homes and how this affect the outcome of decisions on energy measures concerning aesthetical appearance of buildings (Sunikka-Blank and Galvin, 2016).

As a part of this study, a workshop with representatives from different disciplines, such as architecture, cultural heritage, building physics, project management, indoor air quality, property developer, pointed out several areas where SIM applied to the interior of buildings would be the preferred choice of insulation. Interior decorations might also be preserved with SIM, and if U-values are substantially improved, even the heating systems (radiators) that affect furnishing of a room can be re-designed, which could create increased value for the user of the building.

3.3 Legislation on energy and heritage values

Energy efficiency measures on the building stock in Sweden are not new, but has been around since the 18th century (Antell and Paues, 1981). This was especially common in areas with iron ore handling and other energy-intensive production. The transition from having wooden roofs to peat roofs, and that stone houses were built instead of wooden houses, was due to that the forest had to be used in industry and no longer as building material. At the end of the 18th century, the tile stove was invented in Sweden which increased the energy efficiency and saved large amounts of wood. During the 1950s and 1960s, energy supply increasingly came from imported energy, and was based on oil and uranium.

The first building legislations in Sweden were implemented in 1946 (IEA, 2013) and the first energy use requirements were introduced in 1975 after the oil crisis in 1973-1974. The requirements were specified with maximum U-values and demands on the airtightness for different building parts. The building codes were developed during the following years, tightening the demands on the energy use. The codes have the same requirements for new developments and retrofitted buildings, and since 2006 the code is based on a performance criterion which is a maximum level on the energy use of the building and the average thermal transmittance (U-value) of the building

envelope. The building regulations (Boverket, 2016) for new multi-family buildings in the region of Gothenburg demand an energy use of maximum 75 kWh/m² and an average U-value of maximum 0.4 W/m²K (April 2017). For buildings heated by electricity (e.g. heat pumps), an energy use of maximum 45 kWh/m² and an average U-value of maximum 0.4 W/m²K (April 2017). This energy use includes energy for heating, domestic hot water and facility electricity. When renovating a building the measure should not be detrimental on the energy performance. However, if other technical requirements, such as a health aspect and a good indoor environment, cannot be fulfilled, the energy performance can be worse than before the renovation.

The legislations concerning durability and moisture performance (Boverket, 2016) are less specific. For example, the air tightness of the building envelope should be enough to fulfil the energy performance requirements. For materials in the construction the critical moisture content should not be exceeded. This is the limit where moisture does not cause damages that influence the requirements on hygiene or health. If the critical moisture content is not well known, a relative humidity higher than 75% should not be allowed in materials and products where mold and bacterium can grow. Generally, these requirements should be fulfilled by both qualitative (standards, handbooks) and quantitative (calculations, lab testing) investigations.

With the present legislation, a measure should respect the character of the building (proportions, shape, volume, materials, workmanship, color, attention to details and detail level) to be considered acceptable (Boverket, 2018). It is also important to preserve details essential to the building's character. The Swedish legislations prohibits only the degradation of a building's cultural values. This can make it difficult to legally enforce the recreation of cultural values in a building if those values were degraded in the past. There are also few means to hinder changes of original details in a building's interior. A building can be considered valuable if it clarifies earlier societal conditions, the societal development, is a source of knowledge of older materials and technologies, has special aesthetic qualities, or has a high level of ambition for architectural design. As a general recommendation or rule of thumb, any building in Sweden from before 1920 can today be considered valuable, if it has its main characters preserved.

The requirements on energy efficiency and the subsidies that were enforced in the past have led to renovation measures in the past which can now be questioned from a cultural heritage perspective. Often, it was not necessary with a building permit to renovate buildings towards the courtyard side, while there were harder requirements on the street façade. There are several examples on how additional insulation has been applied on buildings in the central parts of cities, particularly in buildings with brick masonry as the load-bearing structure from the 1870-1930s (Lång and Sandgren, 2016). Often the insulation ended one floor above street level since subsidies was only given for the upper floors. This gives an extension of the base of the building which could be solved by adding e.g. lightweight concrete blocks on the exterior of the wall.

4 Energy efficiency of the thermal envelope

Around two thirds of the heat losses in Swedish multi-family buildings arise from transmission losses through the building envelope (Boverket, 2010). Therefore, all measures that increases the energy performance of the building envelope should be investigated to find possible measures that may also be cost efficient. Common renovation measures in multi-family buildings include: improved thermal envelope insulation for attic floor, basement walls and exterior wall; improved new windows; efficient electrical appliances and lighting; resource-efficient taps; glazed enclosed balcony systems; and exhaust air ventilation heat recovery systems (Tommerup and Svendsen, 2006).

As described above, the Swedish building code requires an average U-value of $0.4 \text{ W/m}^2\text{K}$ for new single and multi-family buildings. The demands for renovation are slightly differently expressed. In case the energy use for new buildings cannot be met, the aim shall be a wall U-value of maximum $0.18 \text{ W/m}^2\text{K}$. The U-value of exterior walls in the Swedish building stock is shown in Figure 2, divided in different building age groups (Österbring, 2019). There is a substantial amount of buildings from the 1930s or older that have very high wall U-values. Additional wall insulation would significantly decrease the U-value of these walls. As an example, 5 cm of insulation (with a thermal conductivity of $0.036 \text{ W/(m}\cdot\text{K)}$) would decrease a wall U-value from $1.2 \text{ W/m}^2\text{K}$ to $0.45 \text{ W/m}^2\text{K}$ i.e. by more than 60%.

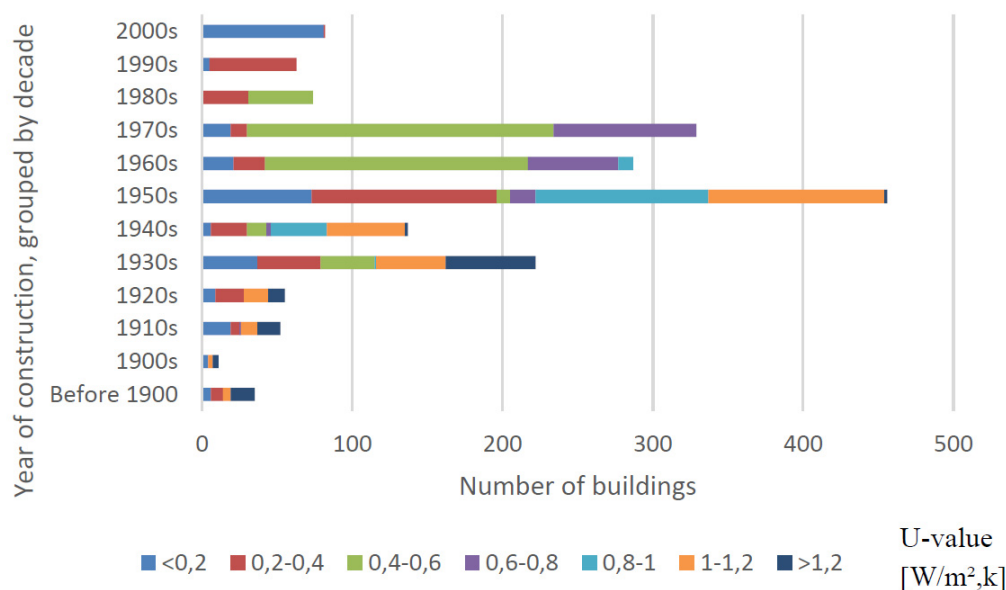


Figure 2. Distribution of U-value of walls for buildings in the municipal housing stock grouped by year of construction (Österbring, 2019).

In a Danish investigation, the so-called P-factor is used to describe heat losses through a building component per degree temperature difference and per heated floor area (as opposed to per component area as in U-value). Figure 3 shows the P-factor for different building parts and different age groups. Like the previous example, walls in older buildings (from 1960 or before) show high heat losses and, consequently, there is a large potential to decrease the energy use by adding insulation in the external walls, either on the interior or exterior side.

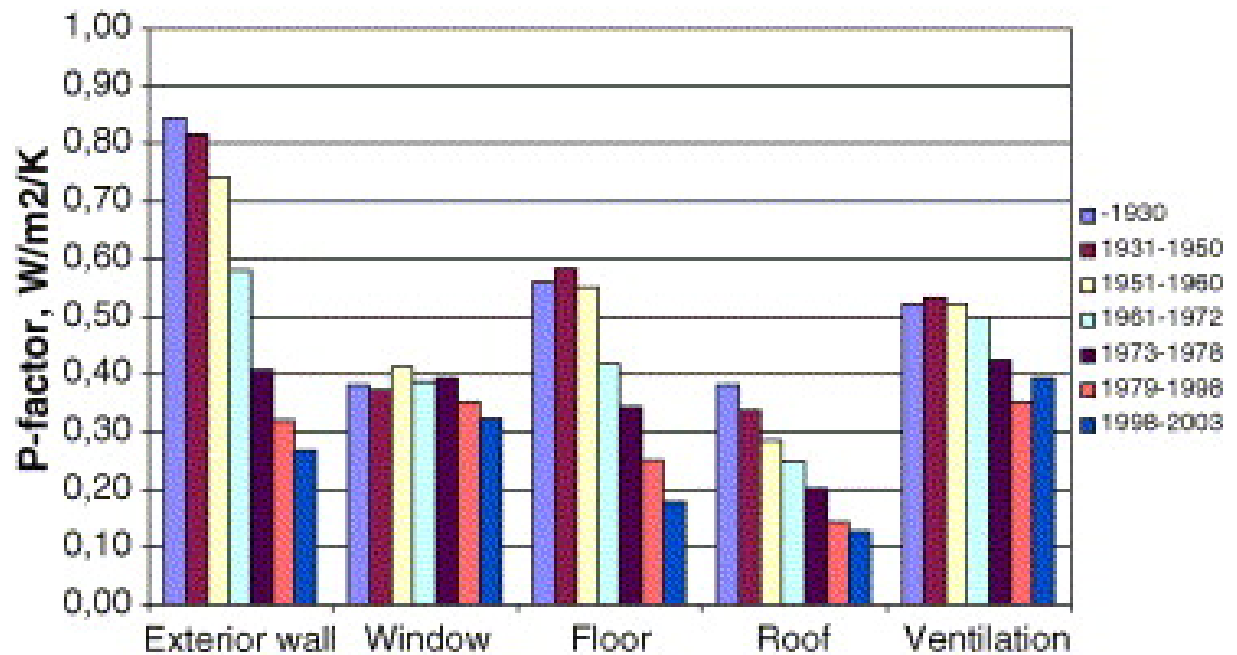


Figure 3. Average heat loss per temperature difference in the Danish residential building stock depending on year of construction, normalized by heated floor area (Tommerup and Svendsen, 2006).

4.1 Potential energy use reduction

There are many examples of simulated energy savings when renovating but there are few examples where the energy use was measured. In Femenias et al. (2018), two renovations are described, one building from 1937, (renovated 1970 and 2016, 36 apartments) and one building from 1938 (renovated 1970). In both buildings, the renovations included several steps, for example additional insulation and new windows. The energy use (as defined in the energy performance certificate, EPC) decreased by 40% and 29% respectively.

Another example of adding insulation is described in (Johansson et al., 2014a; Johansson et al., 2014b). Here, a SIM (vacuum insulation panel, VIP) was used as additional insulation in listed buildings. Calculations showed that it was possible to reduce the energy use by 20-30% when adding vacuum insulation panels on the exterior of the façade. If all buildings from before 1945 would be renovated to the same energy performance, up to 4-6 TWh could be saved annually in Sweden, and 14-21 TWh in Europe. SIM are beneficial to use in renovation projects since it increases the thermal performance of the building envelope without increasing the thickness of the insulation layer as much as when using conventional insulation materials.

4.2 Thermal transmittance and thermal bridges

Adding insulation to a previously non-insulated building component will affect the hygrothermal behavior of the component. Thermal evaluation of the additional insulation needs to be done with respect to energy use, which in turn is affected by thermal transmittance (U-value), thermal bridges and air leakage. The thermal bridges can cause interior condensation and is usually a larger problem when applying interior insulation. When the hygrothermal conditions are evaluated, several different phenomena are of interest: moisture conditions in the component (in parts where

organic materials are present), condensation risk in the component, the impact of existing vapor tight layers in the component and frost damage. When adding insulation to an existing building, there is also a need to discuss interior and exterior surface treatments, such as plaster and water repellents treatments.

Usually, the insulation is added to decrease energy use and increase thermal comfort. When the insulation is added to the outside, it is usually easier to apply the insulation without creating thermal bridges, except for balconies. However, if there is a wish to preserve the exterior of the building, interior insulation is an option. Super insulation materials are, due to the smaller required thickness, often suitable to use at thermal bridges, for example around windows, in ceilings to preserve room height, at point thermal bridges such as wall ties made of steel. However, the interior insulation is disrupted by floors and other construction details, which results in thermal bridges, see Figure 4.

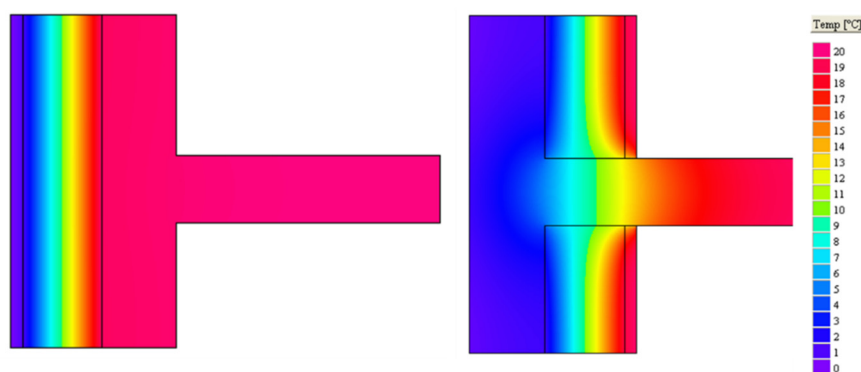


Figure 4. Example of a temperature profile at a wall/floor connection with exterior insulation (left) and interior insulation (right).

The interior surfaces at thermal bridges when using interior insulation will be lower in wintertime compared to the original construction. This can result in problems with thermal comfort and will also result in increased energy use. If the thermal bridge is substantial (or the moisture load indoor is large), this can also result in interior condensation. In a few cases, it is beneficial to keep the thermal storage capacity of the old wall and for that reason choose external insulation. Such cases can occur if there are large temporary internal heat loads (by for example people, machines or incoming solar radiation through large windows).

4.3 Moisture conditions changed by additional insulation

The additional insulation can affect the moisture conditions in several ways with the following pros and cons for interior and exterior insulation. With respect to moisture in the air, the wall with added insulation on the interior will be colder and moister. This can also increase the risk for freeze-thaw damages at the exterior surface. Exterior additional insulation will make the original wall warmer and dryer but is negative when comes to cultural heritage aspects as it in most cases hides the original wall. In some cases, the old exterior façade layer can be removed when the exterior insulation is applied and then reinstalled or replaced by a similar façade material.

When applying additional insulation to a building component, it is essential to investigate the existing wall to determine if and where there are moisture tight layers

and to plan the renovation accordingly. There are two main principles concerning moisture properties of a building component:

1. the inner part (usually warmer and moister in Sweden) shall be more moisture tight than the outer part, to allow drying to the exterior, and
2. two moisture tight layers in a component shall be avoided since moisture can be trapped between them.

In the case of interior insulation, it might be necessary to apply additional surface protection on the outside with respect to water intrusion. The protective layer can be plaster or a water repellant treatment. The water repellant treatment should be vapor open so that moisture diffusion from the inside is not trapped in the wall. It is also important to ensure that there are no cracks or other damages in the façade when the repellant is applied. Plaster is available in many varieties, with different thermal properties and vapor permeabilities. For more information on plaster in connection with additional insulation, see (Sandin, 2008).

Water transport in a brick wall (or other porous material) can lead to salt being deposited (salt efflorescence) on the wall surfaces. The salt can originate from the brick or materials stored in the building, but more commonly from water in the ground. For the latter, the water transport needs to be hindered, often by improved drainage around the foundation, but also by introducing a capillary breaking layer between the ground and the wall. In case of salt from bricks, this source can decline with time and when deposited at the surface, it can also be brushed off. However, salt deposition should be avoided since it deteriorates the masonry and rapidly leads to damages to the construction.

Finally, moisture in building parts will also affect the thermal resistance of the materials in the component. In the case of brick, the thermal conductivity can increase by more than 50% (SBUF, 2016).

4.4 Volume change by temperature and moisture changes

As described above, additional insulation will affect the temperature and moisture conditions of a building. Interior insulation will leave the exterior surface more exposed to varying temperatures (mainly due to solar radiation). All building materials change in volume when subjected to changes in temperature or moisture conditions. Restraints to these volume changes can cause stresses and result in damages, cracks and deterioration. This can also result in cracks, where building elements meet or around openings (such as windows). Exterior insulation will thermally protect the exterior surface. However, exterior insulation can lead to a dryer original wall and resulting cracks. The effect of moisture induced movements are usually of minor importance compared to thermal movements (Andersson, 1979).

In Sweden, it is common with buildings in wood. These buildings are at risk of being damaged by changed heat, moisture and air transport in the construction. In the event of an interior insulation, there is a risk that the cold part of the structure will have an increased moisture level with mold and rot damage as a result. In the case of exterior insulation, there is a risk that the old structure will instead become too dry which can lead to reduced air tightness with increased energy use and reduced thermal comfort as a result (Wahlgren et al., 2015).

4.5 Additional considerations

In addition to considering heritage and building physics (including building performance), there are a few other aspects that need to be considered when deciding on internal or external additional insulation. When applying insulation on the inside of a wall, the available (or rentable) floor area will decrease, and interior decorations can become hidden or distorted. The tenants will also need to move during the renovation. When additional insulation is applied on the exterior, there is a need to change or move the façade, which also requires scaffolding which leads to increased costs.

5 Challenges using interior insulation

There are many examples of problems due to lack of knowledge about how heat, moisture and air are transported and stored in building constructions, especially for renovation. There is a delicate interaction between temperature and humidity in structures. A reduction of the temperature in a construction can result in high humidity (with subsequent performance problems) or increased air movements, which also can cause problems. An energy efficiency measure may also enhance thermal bridges and cause surface contamination due to increased air movement.

Specific to older brick structures is the risk of freeze-thaw damage when exposed to rain and varying temperature conditions. Interior insulation may worsen the risk of these structural damage (Mensinga et al., 2010). Often the structural integrity in older brick buildings is supported by wooden beams that lay in the brick. In the United States, studies on how these wooden beams are affected by an internal insulation have shown that rain and water leakages must be handled correctly in order to avoid damage (Straube et al., 2012). So-called capillary-active materials have been proposed as a solution to the problem (Häupl et al., 2004), while other studies have shown that on the contrary, they absorb even more moisture (Vereecken and Roels, 2014).

In the EU project RIBuild (Robust Internal Thermal Insulation of Historic Buildings), an online survey was carried out among stakeholders in the building industry, i.e. craftsmen, entrepreneurs, building owners and managers (Skovgaard and Bonderup, 2016). The aim was to collect experiences from retrofitting with internal insulation. It was anticipated that moisture safety would be a prominent challenge. The results, mainly from Danish actors, showed that challenges of technical character, challenges in the cooperation, missing information, lacking knowledge were the ones most mentioned. In more detail, participants saw the largest challenges in the vapor barrier, humidity or mold, lack of knowledge, difficult details, fittings, joints, problems with collaboration or the working relationship with other stakeholders, technical or constructional issues, lack of preparation or survey of existing conditions, lack of experience (in particular among the craftspeople), and finally presence of wooden beam ends. There are several different standards on interior insulation that are used by practitioners. Among them are BYG-ERFA (technical leaflets) and information from SBi (Statens Byggeforskningsinstitut) most popular among Danish actors, while guidelines from manufacturers are used extensively by others. For other countries, standards and guidelines exist from BBRI/WTCB/CSTC (BE), WTA Merkblätter, (DE) STBA/SPAB (UK) and BRE (UK).

5.1 Material testing (old constructions)

Working with existing constructions is challenging compared to new construction since the building materials and component are often unknown. There is seldom knowledge on the specific hygrothermal properties of the materials. Before a retrofitting measure is decided this knowledge need to be taken in consideration. This can be done based either on knowledge of materials used in similar buildings or by measuring samples of the materials at the building site, either by destructive or non-destructive testing. These results are then used in hygrothermal calculations to find the proper retrofitting alternatives to investigate further. Lacking knowledge and risk assessment may lead to detrimental results on the overall hygrothermal performance

of the building. Consequences such as surface condensation leading to stains and mold growth are of more aesthetic concern, while freeze-thaw and high moisture contents may be detrimental to the service life of the construction.

As a general guideline there should be no materials with a deviating temperature or moisture expansion on the exterior of the masonry than the masonry itself. This could lead to cracks when the masonry expands and contracts more than the stronger material with less expansion coefficient. The same applies to the moisture resistance where the surface materials generally should have a lower resistance than materials in the wall. Otherwise moisture may be entrapped in the wall, just behind the surface coating. This was done previously with plastic paints applied to wooden constructions in Sweden. The surface got an elevated moisture content with blisters and damage to the wooden construction in many cases. Nowadays, paints with less vapor resistance are prescribed to avoid these problems.

As an example of the material properties of historic brick in Sweden, a case study was performed at the old Papyrus paper mill (Figure 5), south of Gothenburg on the west coast of Sweden. The building is a long narrow brick and concrete building used as a paper machine hall originally erected in 1896. To have correct material properties for the building and thermal performance analyses, the original brick was investigated. Samples of the actual brick from the field study building was removed and brought to the laboratory for testing (Johansson et al., 2018). The size of the bricks is 225 x 110 x 60 mm (length x depth x height) which were constructed in two wythe-masonry with 10 mm hydraulic lime mortar in between the bricks and facing the internal surface. This gives a total wall thickness of 470 mm. Measurements of density, porosity, capillary suction, vapor permeability and thermal conductivity were performed in the laboratory. The results showed that the bricks have a density of 1822 kg/m³ and a porosity of 29% (Johansson et al., 2018).

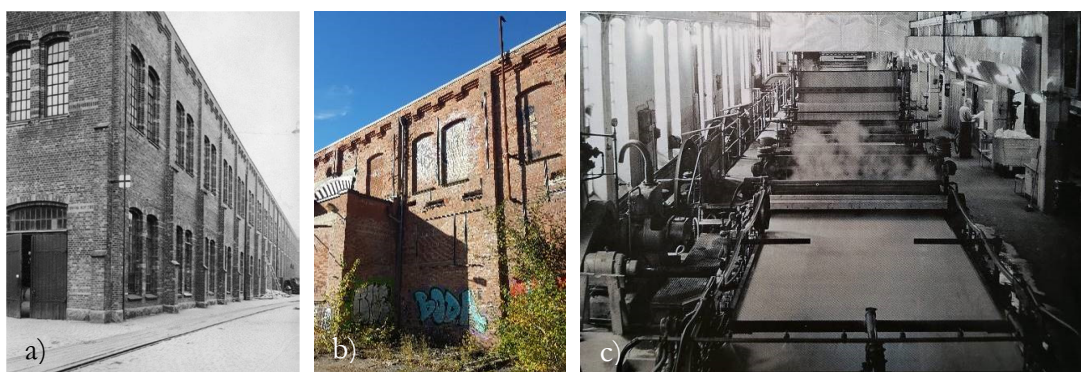


Figure 5. (a) The industrial building from 1896, photo from 1918, (b) The exterior of the tested external wall, (c) Interior of the building when it was in operation as a paper mill.

The capillary suction was tested on three dry samples that were partially immersed in water while the mass was recorded, following SS-EN ISO 15148:2002. The short-term liquid water absorption coefficient A_w was calculated to 0.18 kg/m²s^{0.5} which can be compared new bricks which has 0.16 kg/m²s^{0.5} and 0.19 kg/m²s^{0.5} for new bricks with properties matching old production techniques (Johansson et al., 2014a). The water vapor permeability was measured by the dry cup method. The samples were placed as a lid in a cup with water and an air layer of 100% RH which were placed in a room with constant climate conditions of 20°C and 50% RH according to SS-EN 12086:2013. Three brick samples were measured using this method. The water vapor

permeability was $2.6 \cdot 10^{-6} \text{ m}^2/\text{s}$ which is equivalent to a water vapor diffusion resistance factor (μ -value) of 9.6. This can be compared to other bricks which have a μ -value of 9.5-17, depending on the production method, age, porosity and density (Johansson et al., 2014a).

The thermal conductivity was measured using the transient plane source (TPS) method on a Hot Disk device, SS-EN 22007-2:2008. The TPS sensor used in the setup had a radius of 6.4 mm (0.25 in) and was placed between two samples of the material. A constant electric power was conducted through the spiral with the electric resistance registered and transformed into a temperature increase. The thermal conductivity of the dry brick was $0.61 \text{ W}/(\text{m} \cdot \text{K})$ and the specific heat capacity was $725 \text{ J}/(\text{kg} \cdot \text{K})$.

5.2 Wooden beam ends in brick walls

Connections between different materials need additional attention since these interfaces may be composed of materials with very deviating properties. Both when it comes to diffusion and capillary activity the variability across the interface may entrap vapor or water here. If there are organic materials these may have an elevated risk of mold and dry rot fungi. One specific case for brick buildings is the interface between the masonry and the wooden beam ends. At this location the retrofitting measure may reduce the temperature locally which in its turn may lead to higher moisture levels. Especially when using interior insulation, the conditions are altered in an unfavorable way. Several studies have shown that the risk is elevated at these locations and especially at places with driving rain and freeze-thaw cycles which may cause damage to the exterior surface and consequently reduced water resistance.

There are several measures proposed to reduce the risk for damage at wooden beam ends. This has been studied in both laboratory (Johansson et al., 2014a) and full scale in field. One of the proposed measures is to insulate less around the wooden beam and leave a non-insulated part around this part of the wall (Morelli and Svendsen, 2013). Morelli et al. (2012) investigated this by means of numerical models and found that the risk of damage was significantly reduced if a gap was created between the floor and the insulation layer. In the field, it was found that the method worked, but that special care had to be taken regarding the orientation and exposure of the wall (Harrestrup and Svendsen, 2016). Yet another solution is to heat the sensitive part around the wooden beams (Wegerer and Bednar, 2018). This, however, lead to increased energy use for heating.

It is often a structural engineer that decides on the load-bearing capacity of the wooden beam and masonry in case of damage from moisture ingress. From cultural heritage perspective, wooden beams are important character defining elements for the building and often worth to preserve. Often supply of moisture from the outside is the main problem why a solution may be to apply hydrophobic or water repellent substances on the surface which leads to less moisture penetrating the structure, while it still allows vapor transport (Sandin, 2003).

6 Water repellent treatment of brick façades

As has been described in the previous sections, it is often moisture coming from the outside that is causing the moisture problems in the façade. Therefore, one solution could be to hydrophobize the external surface by using some water repellent surface treatment (impregnation). This should lead to less moisture in the construction. When this project started there were no known studies (for the authors) where internal insulation was combined with water repellent surface treatment of the surface. Therefore, this was investigated in the project by performing a literature survey and hygrothermal modeling of different constructions. To complement these studies with the experiences by Swedish practitioners, five interviews with experts in the field of indoor environmental quality, renovation of buildings and water repellent surface treatments were performed.

There are several different impregnations available which can be applied to the surface of the façade to increase the water repellence. Among the most important drawbacks with these treatments are the limited service life of the treatment and the adverse effects on the performance of the façade if it is not completely free from cracks and other defects. It is crucial to make sure that the masonry surface is in good condition. Otherwise, the impregnation can have adverse effect on the performance of the façade, since the drying out capacity is decreased while water can still enter the cracks and other defects. Slapø et al. (2017) tested four different impregnations on a brick wall with fresh mortar in the laboratory. They recommend great care and consideration when using the substances on brick walls in areas with much driving rain and frequent freeze-thaw cycles.

Many water repellent treatments have high water resistance while the vapor permeability remains quite high. Nevertheless, in all cases the water resistance of the different layers in the construction changes after treatment with water repellent surface treatment. This may lead to less outward drying which need to be considered in a retrofitting project, so that at least inward drying is still possible.

By combining interior insulation with water repellent surface treatment, the amount of rain that enter the façade can be reduced. Lauby (2013) studied a warehouse brick building completed in 1964 in Gothenburg to investigate if it was possible to retrofit the building by using VIPs on the interior. Using a 20 mm thick VIP encapsulated on both sides in 10 mm polystyrene, the theoretical U-value was reduced from $0.58 \text{ W}/(\text{m}^2 \cdot \text{K})$ to $0.16 \text{ W}/(\text{m}^2 \cdot \text{K})$. By using hygrothermal simulations she found that the main challenge would be to take care of the rain load on the façade to reach a satisfactory hygrothermal performance. A water repellent surface treatment made of a silicon resin network was modeled. The treatment makes the surface water repellent while allowing for vapor transfer through the layer. The results from the simulations showed that the moisture content in the wall was reduced significantly with a decreased risk for freeze and thaw damages in the façade. The risk for microbiological growth was also reduced in the organic materials in the wall.

There is a risk for evaporation of white spirit (mineral spirit) from the impregnation. An investigation from the Netherlands shows several mg/m^3 of aliphatic carbohydrates (decane, undecane) were measured inside the buildings in an area of single-family row houses in Nieuw-Amsterdam. The causes for the high concentration of the aliphatic carbohydrates in the indoor air were spraying too large amounts on the façade, cracks in the walls, and wind and solar radiation which drives the white spirit inwards (Bloeman et al., 1990). Also, in Sweden there are examples of high

concentrations of carbohydrates in the indoor air. In a bedroom in a building in the south of Sweden, 6 mg/m^3 was measured where the white spirit had an aromatic content of 17% (Jonsson, 1988).

6.1 Application of water repellent treatments

There exist several standards concerning design and application of water repellent surface treatments. One of them is the German WTA standards that define how the treatments are applied and tested. The standards are more appropriate for natural stone walls than masonry. In brick masonry the penetration of the water repellent substance may be easier to observe than for natural stone constructions. Generally, if the work is done correctly the product should have penetrated maximum 4 cm into the brick and mortar of a water absorbing material. The application would then have a reduction in its performance within 10 to 15 years after the treatment (Wendler and von Plehwe-Leisen, 2008).

The degree of absorption of the façade material can be determined by Carsten tube which measure the capillary water uptake. The minimum capillary water uptake coefficient of the surface should be minimum $1.0 \text{ kg/m}^2\text{h}^{0.5}$ for the treatment to be useful, but it can be argued that it is not efficient for surfaces with below $2.0 \text{ kg/m}^2\text{h}^{0.5}$. Furthermore, Wendler and von Plehwe-Leisen (2008) suggested a number of questions to consider before deciding on applying a water repellent treatment:

- Is the water run-off system, i.e., gutters, down pipes, etc., in working order?
- Can rising damp be eliminated?
- Can condensation water be eliminated inside the building?
- Is the draining system in working order?
- Are the joints in good condition?
- Can hollow spaces, cracks and fissures be eliminated?
- Can all other steps of the conservation/restoration intervention be completed before the treatment?

If not all the above questions have been addressed, the wall should be repaired before the application of a water repellent treatment. It should also be avoided to apply water repellent treatments in materials with presence of hygroscopic salts, sealed surfaces (due to gypsum, lime sinter (calcin), dirty crusts, coating residues, etc.) and, intensive microbial growth (mosses, lichens, fungi) (Wendler and von Plehwe-Leisen, 2008).

6.2 Challenges for practicing engineers in Sweden

This section is based on five interviews with experts in the field of indoor environmental quality, renovation of buildings and water repellent surface treatments. Two of the interviews were conducted by Nilsson (2017) with the focus on experiences of hydrophobic surface treatment on brick facades. The remaining three interviews were performed by the authors. The respondents' answers have been grouped and anonymized to give a more holistic insight into the challenges and experiences from practitioners in Sweden.

Firstly, it is not obvious for some practitioners that hydrophobic treatment and impregnation are the same. When various treatments began to be launched in the late 1970s and early 1980s, many products had low quality. At that time the treatments were used as a solution to many durability problems, often on poor materials. This led to many issues with the construction after the treatment. Before decisions on a treatment can be taken, it is important to review all changes to the property during its lifetime and how the treatment can affect the building. It is often difficult to determine what the wall is made of since there are many different products used for brick masonry constructions in Sweden. It has also changed with time and there are different traditions in different parts of the country.

There is some skepticism that hydrophobic treatments are used in a mechanistic fashion. Especially for renovation of buildings this may be problematic since the treatment is very good theoretically but difficult to apply in practice. First, there is a need to invest in getting the brick façade in good condition so that the hydrophobic treatment is not needed, and in addition, the treatment has a limited service life. If the treatment is needed, the brick façade is probably in poor condition and should be repaired instead. Hydrophobic treatments are often thrown into the renovation package because ‘that’s how you do it’. It is not well known for how long the treatment works as intended, and there are rarely before and after inspections of the façade in connection with the treatment. If there has been moisture damage in the past, water repellent treatments should not be used as it can aggravate the situation. Consequently, the treatment can prevent the deterioration of the brick façade but can at the same time entrap moisture in the façade, worsening existing problems.

Especially there are two concerns pointed out by one of the experts;

1. Microcracks in the façade, which have high capillary suction, are not completely impregnated. This means slower drying by the treatment can lead to damage. Brick façades are normally redone with some 40-year intervals, and cracks can form long before then. The façade is already damaged if it has damp brick. If the brick façade is in good condition, it works well also without the water repellent treatment.
2. The treatment causes changed surface properties of the façade. This can cause flooding since the water is not contained inside the construction as before. Often it is not a good situation with increased stormwater on the ground around the building. It is beneficial with the buffering capacity of brick façades to mitigate stormwater in urban areas.

According to one of the experts on water repellent surface treatments, there are rarely problems after hydrophobic treatments have been applied on façades today. In all projects carried out by another of the experts, they have seen that the façades are still in good condition after the impregnation. Older properties from the 1950s-1960s with decent brick quality and large moisture problems have been impregnated with good results. But it is important to remember that impregnation is not a universal solution and it is important to be careful since the moisture balance and the chemistry of the wall can be changed after the treatment. Furthermore, it is argued that the brick quality is generally poorer nowadays and therefore the risk of problems may be higher today than previously.

According to one of the experts, they have not treated any façades with impregnation for a long time, but it worked well when they last did it. However, the expert stress

the importance that the façade must be correctly maintained. The customer must know that inspections and maintenance is required approximately every 8 years. When the treatment diminishes the façade absorb water unevenly, earlier higher up where it is more exposed to rain and wind, and then it absorbs substantial amounts of water. The mortar and the brick absorb moisture and then water flows internally into the structure. At this stage the moisture is trapped in the construction as the vapor is transported through but not the water. In homogenous brick masonry walls, it will be a moisture accumulation, independent on if it is winter or summer. In some cases, it dries inwards and sometimes outwards. It is important to understand the physics behind the treatment. Unfortunately, this knowledge is not always spread in the business among salespersons and consultants. There are many consultants and companies in the industry who do not understand this but use it on unsuitable façades. It seems the customers do not always understand what is happening and the suppliers do not always tell the full story.

The primary use of the hydrophobic treatment is to get a drier construction since the dry construction is more energy efficient compared to a wet construction. It is most common to use it on brick façades, but there are also companies that use the treatment on plastered buildings. Normally this is done for systems with thick plaster of around 2-3 cm thickness which acts as a water buffer. The underlying construction does not get wet and when it stops raining it dries out. On the other hand, the popular thin plaster systems build 7-8 mm as maximum thickness, but it exists even thinner systems, and only creates rain protection on the façade. This system is known to form microcracks where water can enter (at lamps and such). The water cannot dry at the same speed as it enters which make the system incompatible with hydrophobic treatments.

Homogenous brick buildings constructed 100 years ago are seldom in need of hydrophobic treatment. These are homogenous brick masonry walls of up to 60 cm thickness, which decreases higher up in the building and at the top at least 35 cm homogenous masonry. In that time, they used hydraulic materials, i.e. mortar that allow movements and do not crack so much. This means that the construction is quite porous and absorbs water through joints if not maintained properly. The bricks are normally of high density and very dense. Often the water enters through damaged mortar joints between the bricks. After leakage occur it takes a long time, up to 6 months, to dry out. It would be devastating to apply hydrophobic treatment on such façades. Normally there is very good quality of the brick masonry and therefore do not need to be replaced. These façades can withstand freeze-thaw damage and do not absorb as much moisture.

Buildings from the 1970-1980s in Gothenburg were built with yellow brick in the façade. These buildings are normally 4-5 floors high with bricks that freeze due to lower quality of the brick. The climate with high humidity during a winter day, followed by subzero degrees at night, driving rain, sun, 10°C in the day and then freezes again makes these bricks unsuitable here. There are many freeze-thaw cycles during a winter period and these bricks should not be used in Western Sweden. Normally they freeze in blocks and 1 cm at a time fall. These constructions have an air gap behind the bricks, veneer brick wall, with wall ties made of steel that create the air gap between the insulation and the brick. This works well in theory, but, many constructions do not function properly. It can be the insulation that moves against the exterior wall, absorbs the moisture and transports it into the construction, or bridges

of mortar at every joint where the mortar falls into the air gap. This means that moisture is transported right through the structure in any case.

When microcracks are formed they can be filled by glass crystals that make it denser, this is commonly used for concrete, but also some brick façades can be hydrophobic treated. Especially those façades that were built in the 1980s with very hard cement mortar. This can be too strong so that the brick breaks and cracks due to movement in the façade. Normally, it is not economically reasonable to improve the façade using hydrophobic treatment, but better create another protection outside the façade. If it is possible to rebuild with new bricks, create a ventilated air gap and repair the construction. Often the wall is very cold which means the material does not cope with these conditions.

It is not expected that the hydrophobic treatment increases the risk of freeze-thaw damage to the wall because there is low resistance to water vapor transport. One of the experts only got reports of freeze-thaw damages once, and in that case, it was a design flaw. Furthermore, it seems that most users are positive to use the water repellent treatments in cases where it is needed. A hydrophobic surface treatment is a good solution if the façade is wet, but it is important to remember that all façades are different. The same solution does not work on all façades. The service life is at least 10 years and if damage occur on the wall, it must be repaired and a new treatment done. It is difficult to test and find test objects to evaluate the treatment which makes the service life complicated to predict for different cases.

Salt deposition and salt efflorescence seems to be an unheard problem which is not expected to lead to problems with the construction. If problems would arise in connection with salts in the wall, this would be due to serious design defects. Therefore, it is important to take samples from the façade before treatment is applied. Often many samples are needed, from different height and direction. This gives a good picture of what needs to be addressed and whether the wall can dry out inwards.

Furthermore, it is important to investigate the capillary forces in brick walls and how they can be affected by various factors. For example, there are also large differences between older homogenous brick façades and modern ventilated brick veneer walls. In older constructions, there is always a natural path for the water through capillary forces, even when the wall is plastered. This is not found in brick veneer walls. It is not always the façade causing problems, but other factors such as if the interior surface is wallpapered and painted several times, creating a surface with high vapor resistance. Also, the capillary suction can be hindered if the mortar in the brick masonry decomposes inside the wall.

The type of brick and mortar is important to consider. When it comes to hard-burnt brick, it takes a long time before it gets damp, but it also takes a very long time before it has dried out. Hard-burnt brick is more common in older brick façades compared to modern constructions. The drying of bricks is slower after a hydrophobic surface treatment is applied, and the first floor is critical regarding impregnation due to the proximity to moisture of the surrounding ground. Should cracks occur, it is important to repair these before the treatment is applied, otherwise the crack growth will accelerate.

The safest water repellent treatment is to apply plaster on the brick surface on the outside so that it becomes a capillary tight layer. Before that, damaged stones should be replaced, and the joints must be whole and complete. It is important to seal properly around windows. The treatment can normally be applied on all types of

bricks, it will have the same function. One of the experts experienced renovation projects carried out despite warnings as there were cracks in the facade and split stones. This locked in the damage and it is just a matter of time before the treatment will cause problems.

The risks of damaging character defining elements of the building after a treatment cannot be ignored. The risk depends on whether it is the construction itself, or the aesthetics and expression that carries the cultural values. Which interventions that can be conceived are determined by how valuable the brick structure itself is. This must be weighed for and against separately in each case. According to PBL (Swedish planning and building act), it is the municipality's administrative antiquarian that makes the assessment of what is reasonable in the end.

7 Discussion and future studies

In this report several topics have been raised concerning energy efficiency measures and especially interior insulation using SIM in historic buildings. Furthermore, the possibility of using water repellent treatments on brick façades was explored through interviews with experts in the field.

Normally, the construction projects today are very cost sensitive which requires standard solutions. There is not much time for neither planning or construction of unconventional constructions. However, today already more energy efficient insulation products are used, such as PIR (polyisocyanurate) and phenolic foam insulation, which shows there is a demand from the industry to find new solutions. Public property owners have tough energy requirements which makes mitigation of thermal bridges increasingly important. For example, window fasteners can be an interesting area for SIM. It would also be interesting to see products with SIM integrated, such as prefabricated concrete elements where they are more protected.

It is problematic if millimeter precision is required when using these materials. Modern façade materials, such as boards, require little adaption and work on the construction site. At present, there is a trend in the Swedish construction industry to automatize the work and make as much ready at the factory where there is more control of the production which could increase the feasibility to use SIM in factory produced assemblies.

From the discussions in the reference group it is evident that the practical limitations of using and introducing new materials to the market does not only have to do with the technical compatibility with existing materials and the cost of the material itself, but also has to do with contractual issues such as warranties and responsibility in case of damage. Also, requirements must be made in the procurement where meticulous planning is needed to keep costs down later in the project. This is a matter of competence for the procurement stage.

- Who takes responsibility if things go wrong?
- Who takes the cost and who gets the possible profit?

It is important to consider what happens to the warranty when new materials are introduced. It is also important with a product standard to make the materials more widely used. However, this is outside of the scope of the current study.

There is work going on internationally since 2013 on a new standard for VIP. A European standard prEN 17140 (Thermal insulation products for buildings - Factory made Vacuum Insulation Panels VIP - Specification) will soon be released on a final referral round while the ISO standard is out on yet another referral round. When these standards are launched, VIP may be more useful to the industry with a clear definition and performance requirements.

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